Interfaces in Thermoplastic Composites Probed by Laser-Induced Acoustic Emission

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The mechanical properties and durability of carbon fiber composites depend not only on the properties of the constituent fiber and matrix but also on the quality of the interfacial bond. Many of the techniques for evaluating this bonding rely on model (e. g. single filament) composites (1-3). Besides being difficult to prepare and test, these specimens are subject to the criticism that they may not reflect actual behavior in a full-scale composite with a reasonable volume fraction of fibers. This is an important consideration especially in thermoplastics, whose morphology may be sensitive to processing details.

A few interface measurement techniques use actual composites, but are destructive (4-6). The thermoacoustic technique of Wu, on the other hand, is applied to actual laminates and probes a very small area (7). Thus, although it is not entirely nondestructive, it could be used for quality control of manufactured parts, for example.

This letter reports on application of Wu's technique to some well-characterized amorphous thermoplastic composites.

Unidirectional composite panels were fabricated by molding thoroughly dried solution-impregnated, drum-wound prepreg in matched metal molds. Composite fiber volume fractions were calculated from prepreg fiber areal weights. The materials studied are listed in Table I.* The two fibers chosen have similar nominal tensile properties, but embedded single-filament tests (8) and fracture toughness results (9,10) indicate that they differ in their affinities for thermoplastic resins.

An unfocused 6 watt Argon Ion laser beam was trained on a specimen for 10 seconds. Acoustic emission (AE) was detected by a 150 kHz resonant AE sensor (Physical Acoustics Corporation model R15). The signals were amplified 40 dB by a preamplifier (Physical Acoustics Corporation model 1220A) which had a bandpass filter of 100-300 kHz. The distance from the center of the laser spot to the center of the sensor was nominally 2.9 cm along the fiber direction. The detected signals were analyzed with a conventional AE system (Physical Acoustics Corporation Locan-AT) which had a system gain of 20 dB and a threshold set at 26 dB. The AE system was activated 10 seconds before the laser was turned on to verify that extraneous noise was not being detected. AE threshold crossing counts were monitored during the laser heating period and for approximately 110 seconds afterwards. The total cumulative counts from two experiments at different locations on the same panel were averaged.

A plot of the cumulative counts versus time data from the measurements on the PPO matrix samples is shown in Figure 1. In this figure, zero on the time scale corresponds to the point at which the laser was turned on. Acoustic emission began shortly after the shutter was opened. Emissions continued at a lower rate for approximately 30 seconds after it was closed, and then slowed further. After the test, a raised blister several millimeters in extent surrounded the laser spot. A polished section through the laser spot shows (Fig. 2) that the laser damage penetrated through several plies.

Table II shows the correlation between total counts and composite transverse flexural strength, which is thought to be a reliable indicator of fiber/matrix interfacial bond strength (11). We note first of all that the thermoacoustic data are not comparable between the two resin systems. This was expected since the specimens were different in size and shape. For each resin system, however, the material with the lower strength gave the higher acoustic output. The relative magnitude of the acoustic output does not seem to directly reflect the mechanical strength, but there is no a priori reason that it should.

These results suggest that the technique may be a useful tool to assess interfacial bonding in thermoplastic composites. Future studies will seek to identify the mechanisms that lead to acoustic emission under these conditions.

References

[1] Broutman, L. J.: "Measurement of the Fiber Polymer Matrix Interfacial Strength," Interfaces in Composites, ASTM STP 327, Amer. Soc. for Testing Materials, Philadelphia, PA, 1963, p. 133.

[2] Miller, B., Muri, P. and Rebenfeld, L.: "A Microbond Method for Determination of the Shear Strength of a Fiber/Resin Interface," Compos. Sci. and Technol., 28, 17(1986).

[3] Drzal, L. T., Rich, M. J. and Lloyd, P. F.: "Adhesion of Graphite Fibers to Epoxy Matrices-I The Role of Fiber Surface Treatment," J. Adhesion, 16, 1(1983).

[4] Mandell, J. F., Grande, D. N., Tsiang, T. H. and McGarry, F. J.: "Modified Microdebonding Test for Direct Insitu Fiber/Matrix Bond Strength Determinations in Fiber Composites," ASTM STP 893, Test and Design, 7th Conf., J. Whitney, ed., Philadelphia, PA, 1986, p. 87.

[5] Carman, G. P. , Lesko, J. J., Reifsneider, K. L. and Dillard, D. A. "Micromechanical Model of Composite Materials Subjected to Ball Indentation", J. Compos. Mater. 27(3), 303 (1993)

[6] Sato, N and Kurauchi, T., "Effect of fibre sizing on composite interfacial deformation studied by thermo-acoustic emisssion measurement", J. Mater. Sci. Lett. 11, 362 (1992)

[7] Wu, W. L.: "Thermoacoustic Technique for Determining the Interface and/or Interply Strength in Polymeric Composites," SAMPE J., 26(2), 11(1990).

[8] W. D. Bascom, R. M., Jensen and L. W. Cordner, Int'l. Conf. on Composite Materials (6th: 1987, London) F. L. Mathews, ed. London: Elsevier, p. 5, 424.

[9] J.A. Hinkley, J. Reinf. Plast. Compos. 9, 470 (1990)

[10] Hinkley, J.A. "Effect of Fiber-Matrix Adhesion on Interlaminar Fracture Toughness of Graphite Thermoplastic Composites," in Composite Applications, T. L. Vigo and B. J. Kinzig, eds. VCH Publishers, New York, 1992, p.267
[11] Adams, D. F., King, T. R. and Blackletter, D. M.: Compos. Sci. and Technol., 1991.

Table 1: Composite Materials

Fiber	Matrix	Fiber Volume (%)	Panel Thickness (mm)
AS4[a]	PC[c]	59.4	3.5
XAS[b]	PC	63.2	3.6
AS4	PPO[d]	49.7	1.9
XAS	PPO	50.5	2.0

[a] Hercules Inc.

[b]Hysol Grafil.

[c]Bisphenol A polycarbonate (GE, Lexan 101).

[d]Ply(2,6-dimethyl phenylene oxide) (GE, Noryl).

* Certain commercial materials are identified in this letter in order to specify adequately the experimental procedure. In no case does such identification imply endorsement by NASA.

Table 2: Thermoacoustic and Mechanical Results

Fiber	Matrix	90 Degree Flexural Strength, MPa (+/- standard deviation)	Acoustic Counts
AS4	PC	42.0 +/- 0.6	400
XAS	PC	14.2 +/- 1.4	520
AS4	PPO	66.4 +/- 1.6	3600
XAS	PPO	79.9 +/- 3.2	2100

Figure 1 Thermo-acoustic output from two materials systems as a function of time. Laser was on for the first 10 seconds.

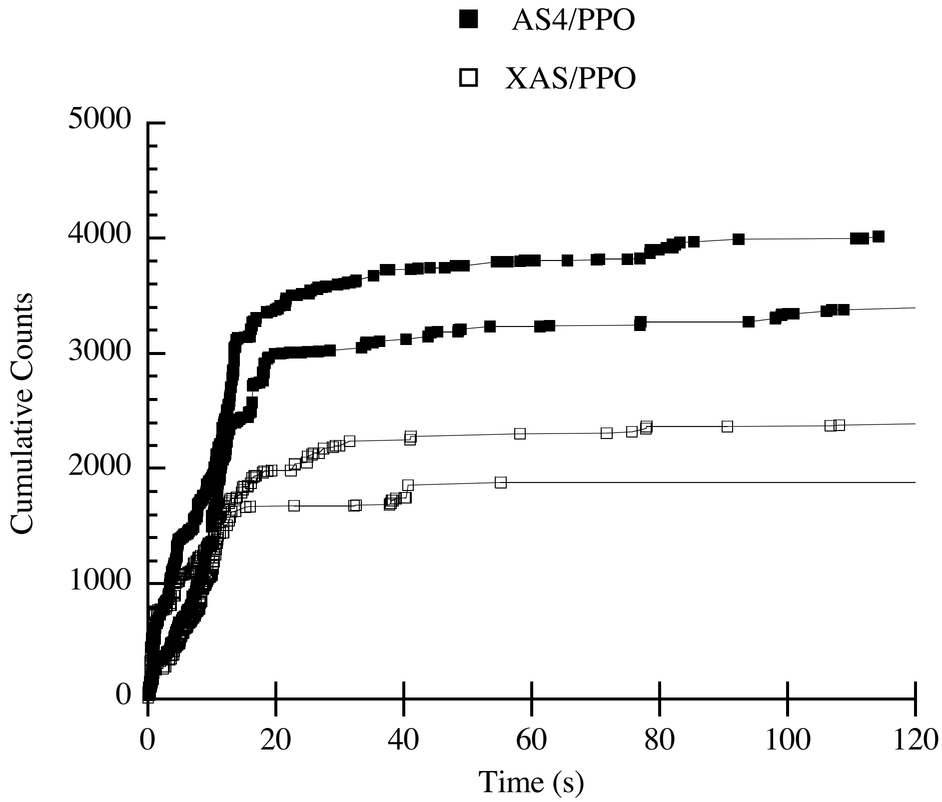

Figure 2 Optical micrograph of polished cross-section of specimen after test. Full laminate thickness (1.9 mm) is shown.